Results

MANOVA

Introduction

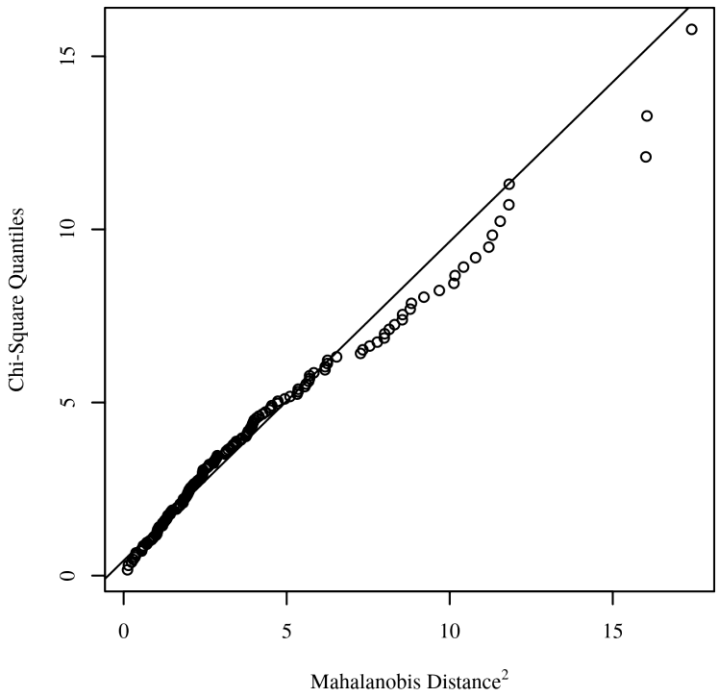
A multivariate analysis of variance (MANOVA) was conducted to assess if there were significant differences in the linear combination of Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width between the levels of Species.

Assumptions

Multivariate normality. To assess the assumption of multivariate normality, the squared Mahalanobis distances were calculated for the model residuals and plotted against the quantiles of a Chi-square distribution (DeCarlo, 1997; Field, 2017). In the scatterplot, the solid line represents the theoretical quantiles of a normal distribution. Multivariate normality can be assumed if the points form a relatively straight line. Strong deviations could indicate that the parameter estimates are unreliable and multivariate normality cannot be assumed. The scatterplot for normality is presented in Figure 1.

Figure 1

Chi-square Q-Q plot for squared Mahalanobis distances of model residuals to test multivariate normality.



Homogeneity of covariance matrices. To examine the assumption of homogeneity of covariance matrices, Box's *M* test was conducted. The results were significant based on an alpha value of .05, $\chi^2(20) = 140.94$, $p < .001$, indicating that the covariance matrices for each group of Species were significantly different from one another and that the assumption was not met.

Multivariate Outliers. To identify influential points in the model residuals, Mahalanobis distances were calculated and compared to a χ^2 distribution (Newton & Rudestam, 2012). An outlier was defined as any Mahalanobis distance that exceeds 18.47, the 0.999 quantile of a χ^2 distribution with 4 degrees of freedom (Kline, 2015). There were no outliers detected in the model.

Absence of multicollinearity. A correlation matrix was calculated to examine multicollinearity between the dependent variables. The following variable combinations had correlations greater than 0.9 in absolute value, suggesting possible singularities: (Petal_Length, Petal_Width). Singularities occur when two variables are identical or nearly identical. When

correlations greater than 0.9 or less than -0.9 are present, the results of the analysis may be moderately biased. The correlation matrix is presented in Table 1.

Table 1

Correlations between Dependent Variables

Variable	1	2	3	4
1. Sepal_Length	-			
2. Sepal_Width	-.12	-		
3. Petal_Length	.87	-.43	-	
4. Petal_Width	.82	-.37	.96	-

Results

The main effect for Species was significant, $F(8, 290) = 53.47$, $p < .001$, $\eta^2_p = 0.60$, suggesting the linear combination of Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width was significantly different among the levels of Species. The MANOVA results are presented in Table 2.

Table 2

MANOVA Results for Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width by Species

Variable	Pillai	*F*	*df*	Residual df	*p*	η_p^2
Species	1.19	53.47	8	290	< .001	0.60

Posthocs. To further examine the effects of Species on Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width, an analysis of variance (ANOVA) was conducted for each dependent variable.

ANOVA

Introduction

An analysis of variance (ANOVA) was conducted to determine whether there were significant differences in Sepal_Length by Species.

Results

The ANOVA was examined based on an alpha value of .05. The results of the ANOVA were significant, $F(2, 147) = 119.26$, $p < .001$, indicating there were significant differences in Sepal_Length among the levels of Species (Table 3). The eta squared was 0.62 indicating Species explains approximately 62% of the variance in Sepal_Length. The means and standard deviations are presented in Table 4.

Table 3

Analysis of Variance Table for Sepal_Length by Species

Term	*SS*	*df*	*F*	*p*	η_p^2
Species	63.21	2	119.26	< .001	0.62
Residuals	38.96	147			

Figure 2

Means of Sepal_Length by Species with 95.00% CI Error Bars

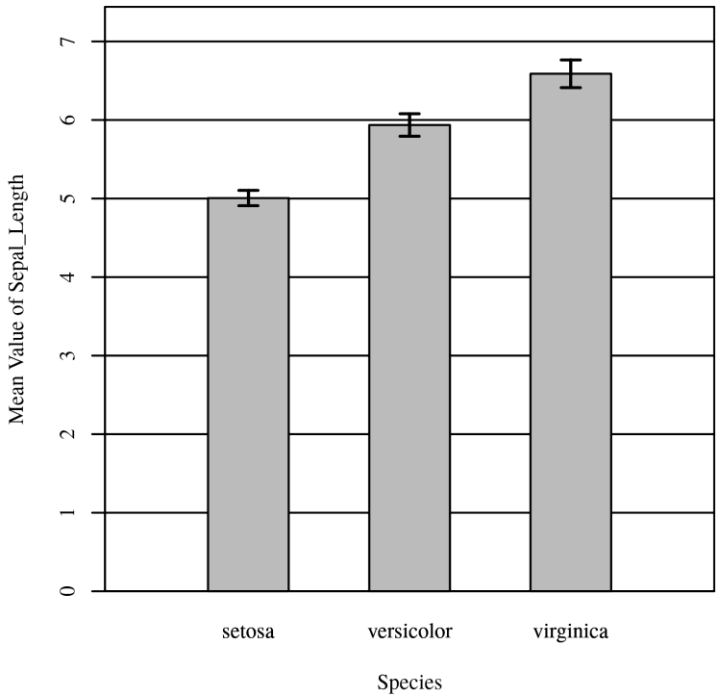


Table 4

Mean, Standard Deviation, and Sample Size for Sepal_Length by Species

Combination	*M*	*SD*	*n*
setosa	5.01	0.35	50
versicolor	5.94	0.52	50
virginica	6.59	0.64	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

ANOVA

Introduction

An analysis of variance (ANOVA) was conducted to determine whether there were significant differences in Sepal_Width by Species.

Results

The ANOVA was examined based on an alpha value of .05. The results of the ANOVA were significant, $F(2, 147) = 49.16$, $p < .001$, indicating there were significant differences in Sepal_Width among the levels of Species (Table 5). The eta squared was 0.40 indicating Species explains approximately 40% of the variance in Sepal_Width. The means and standard deviations are presented in Table 6.

Table 5

Analysis of Variance Table for Sepal_Width by Species

Term	*SS*	*df*	*F*	*p*	η_p^2
Species	11.34	2	49.16	< .001	0.40
Residuals	16.96	147			

Figure 3

Means of Sepal_Width by Species with 95.00% CI Error Bars

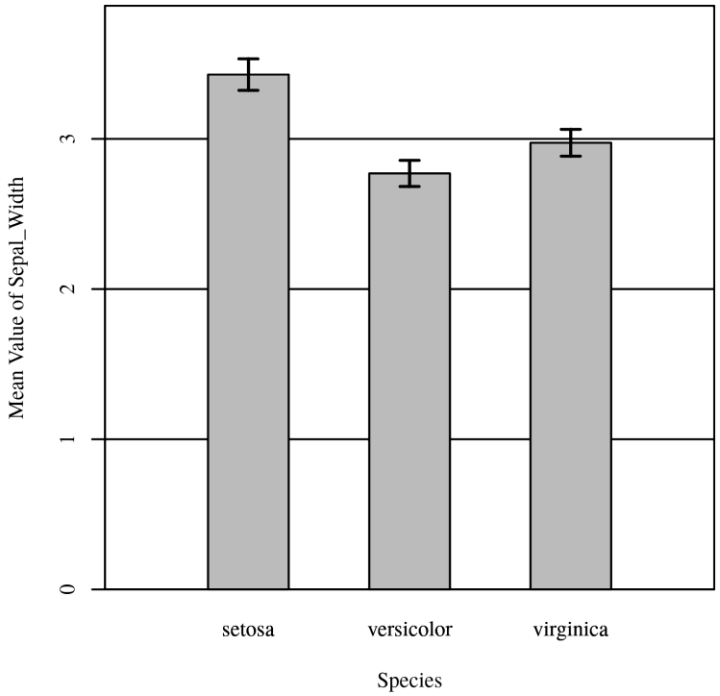


Table 6

Mean, Standard Deviation, and Sample Size for Sepal_Width by Species

Combination	*M*	*SD*	*n*
setosa	3.43	0.38	50
versicolor	2.77	0.31	50
virginica	2.97	0.32	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

ANOVA

Introduction

An analysis of variance (ANOVA) was conducted to determine whether there were significant differences in Petal_Length by Species.

Results

The ANOVA was examined based on an alpha value of .05. The results of the ANOVA were significant, $F(2, 147) = 1{,}180.16$, $p < .001$, indicating there were significant differences in

Petal_Length among the levels of Species (Table 7). The eta squared was 0.94 indicating Species explains approximately 94% of the variance in Petal_Length. The means and standard deviations are presented in Table 8.

Table 7

Analysis of Variance Table for Petal_Length by Species

Term	*SS*	*df*	*F*	*p*	η_p^2
Species	437.10	2	1,180.16	< .001	0.94
Residuals	27.22	147			

Figure 4

Means of Petal_Length by Species with 95.00% CI Error Bars

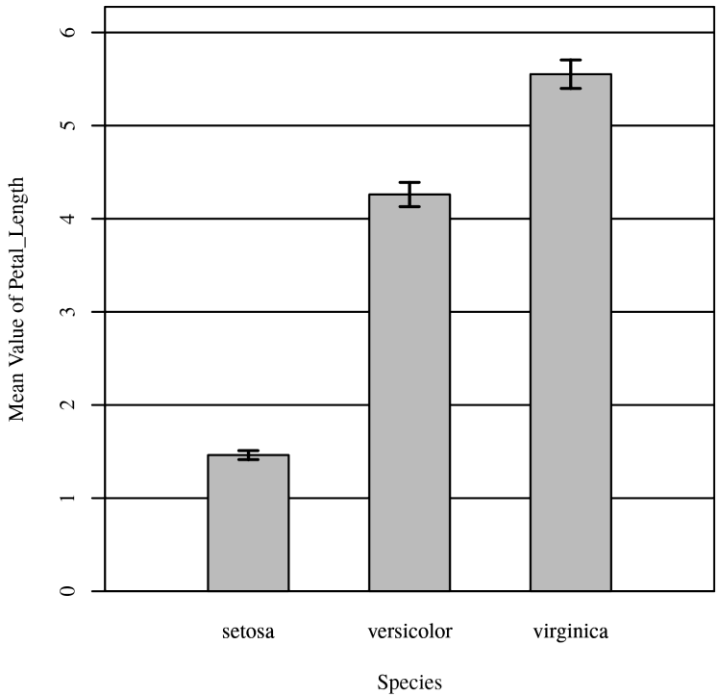


Table 8

Mean, Standard Deviation, and Sample Size for Petal_Length by Species

Combination	*M*	*SD*	*n*
setosa	1.46	0.17	50
versicolor	4.26	0.47	50

virginica	5.55	0.55	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

ANOVA

Introduction

An analysis of variance (ANOVA) was conducted to determine whether there were significant differences in Petal_Width by Species.

Results

The ANOVA was examined based on an alpha value of .05. The results of the ANOVA were significant, $F(2, 147) = 960.01$, $p < .001$, indicating there were significant differences in Petal_Width among the levels of Species (Table 9). The eta squared was 0.93 indicating Species explains approximately 93% of the variance in Petal_Width. The means and standard deviations are presented in Table 10.

Table 9

Analysis of Variance Table for Petal_Width by Species

Term	*SS*	*df*	*F*	*p*	η_p^2
Species	80.41	2	960.01	< .001	0.93
Residuals	6.16	147			

Figure 5

Means of Petal_Width by Species with 95.00% CI Error Bars

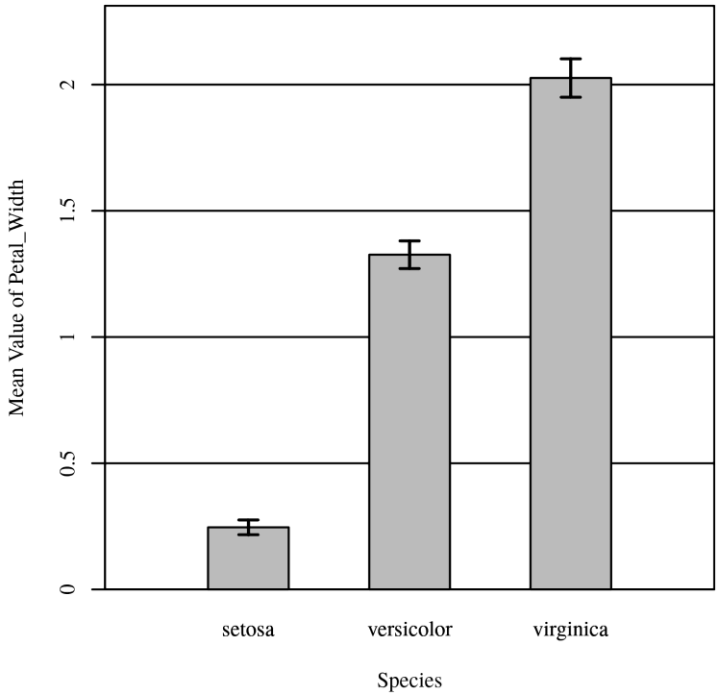


Table 10

Mean, Standard Deviation, and Sample Size for Petal_Width by Species

Combination	*M*	*SD*	*n*
setosa	0.25	0.11	50
versicolor	1.33	0.20	50
virginica	2.03	0.27	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

References

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Newton, R. R., & Rudestam, K. E. (2012). *Your statistical consultant.* Sage Publications.

Glossaries

MANOVA (Multivariate Analysis of Variance)

The MANOVA is used to assess for differences in two or more scale, dependent variables by a nominal independent variable(s). The purpose of conducting a MANOVA is to determine if there are any simultaneous differences among the set of dependent variables by an independent variable(s). This method of analysis helps reduce the likelihood of committing a Type I error compared to conducting separate ANOVAs for each dependent variable. This test partitions the variability in the dependent variables to compute the *F* ratio, which is used with the *df* to compute the *p*-value (i.e., significance level). A significant result for this test indicates that there is a statistically significant difference between groups for at least one of the dependent variables. If significance is found for the MANOVA, then the results of individual ANOVAs are interpreted to determine which dependent variables had significant differences. For significant individual ANOVAs, further pairwise comparisons may be conducted to determine specifically which groups differed from each other. The statistical assumptions of MANOVA include independence of observations, normality, equality (or homogeneity) of variance, and equality of covariance. Additionally, the dependent variables should be related to each other. Correlations can be conducted to determine if there are significant relationships among these variables.

Fun Fact! *A multivariate analysis (such as a MANOVA) typically means an analysis with more than one dependent variable. Analyses with multiple independent variables but only one dependent variable (such as multiple regression) are not true multivariate analyses.*

Box's M Test: Test to assess if the assumption of equality of covariance is met; if significance is found, the covariance matrices differ between groups.

Degrees of Freedom (*df*): Refers to the number of values used to compute a statistic; an *F*-test has two values for *df*: the first is determined by the number of groups being compared - 1, and the second is approximately the number of observations in the sample; used with the *F* to determine the *p*-value.

Equality of Covariance: Covariance refers to the correlation among dependent variables, which can be represented in a covariance (correlation) matrix; the covariance matrices should be equal for all groups.

***F* Ratio (*F*):** The ratio of explained variance to error variance; used with the two *df* values to determine the *p*-value.

Multicollinearity: A state of very high intercorrelations or inter-associations among a set of variables.

Multivariate Normality: A set of variables has multivariate normality, when every linear combination of the variables has univariate normality (follows a bell curve).

Outlier: A data point that is abnormally distant from a set of observations.

Partial Eta Squared (η^2_p): Effect size for the MANOVA; represents the proportion of variability in the dependent variables accounted for by the independent variable.

***p*-value:** The probability of obtaining the observed results if the null hypothesis (no differences in the dependent variables by the independent variable) is true.

Residuals: Refers to the difference between the predicted value for the dependent variable and the actual value of the dependent variable.

Type I Error: Rejection of the null hypothesis when the null hypothesis is true; also referred to as a false positive result.

Raw Output

MANOVA with Species by Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width

Included Variables:
Sepal_Length, Sepal_Width, Petal_Length, Petal_Width, and Species

Sample Size (Complete Cases):
N = 150

Homogeneity of Covariance Matrices: Box's M Test
$\chi^2(20) = 140.943$, $p = 3.352 \times 10^{-20}$

Correlation Matrix for Sepal_Length, Sepal_Width, Petal_Length, and Petal_Width

Variable	1	2	3	4
1. Sepal_Length	-			
2. Sepal_Width	-0.118	-		
3. Petal_Length	0.872	-0.428	-	
4. Petal_Width	0.818	-0.366	0.963	-

MANOVA Model Results:

Variable	Pillai	F	df	Residual df	p	η_p^2
Species	1.192	53.466	8	290	9.742×10^{-53}	0.596

Analysis of Variance Table for Sepal_Length by Species

Included Variables:
Sepal_Length and Species

Sample Size (Complete Cases):
N = 150

ANOVA Results:

Term	SS	df	F	p	η_p^2
Species	63.212	2	119.265	1.670×10^{-31}	0.619
Residuals	38.956	147			

Means Table:

Combination	M	SD	n
setosa	5.006	0.352	50
versicolor	5.936	0.516	50
virginica	6.588	0.636	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

Analysis of Variance Table for Sepal_Width by Species

Included Variables:
Sepal_Width and Species

Sample Size (Complete Cases):
N = 150

ANOVA Results:

Term	SS	df	F	p	η_p^2
Species	11.345	2	49.160	4.492×10^{-17}	0.401
Residuals	16.962	147			

Means Table:

Combination	M	SD	n
setosa	3.428	0.379	50
versicolor	2.770	0.314	50
virginica	2.974	0.322	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

Analysis of Variance Table for Petal_Length by Species

Included Variables:
Petal_Length and Species

Sample Size (Complete Cases):
N = 150

ANOVA Results:

Term	SS	df	F	p	η_p^2
Species	437.103	2	1,180.161	2.857×10^{-91}	0.941
Residuals	27.223	147			

Means Table:

Combination	M	SD	n
setosa	1.462	0.174	50
versicolor	4.260	0.470	50
virginica	5.552	0.552	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.

Analysis of Variance Table for Petal_Width by Species

Included Variables:
Petal_Width and Species

Sample Size (Complete Cases):
N = 150

ANOVA Results:

Term	SS	df	F	p	η_p^2
Species	80.413	2	960.007	4.169×10^{-85}	0.929
Residuals	6.157	147			

Means Table:

Combination	M	SD	n
setosa	0.246	0.105	50
versicolor	1.326	0.198	50
virginica	2.026	0.275	50

Note. A '-' indicates the sample size was too small for the statistic to be calculated.